Department of Energy

Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208-3621

FREEDOM OF INFORMATION ACT PROGRAM

February 18, 2015

In reply refer to: FOIA #BPA-2015-00676-F

Reed Bartlett
Bodwell EnviroAcoustics
55 Ocean Drive
Brunswick, ME 04011

Dear Mr. Bartlett:

We have received your request for records under the Freedom of Information Act (5 U.S.C. § 552). Thank you for your interest in the Bonneville Power Administration (BPA). Your request was received in this office on February 13, 2015, and has been assigned control number BPA-2015-00676-F. Please use this number in any correspondence with the agency about your request.

You requested:
Corona and Field Effects programming and coding AND Bonneville Power Administration's 1977 Technical Report ERJ-77-167- Description of Equations and Computer Program for Predicting Audible Noise, Radio Interference, Television Interference, and Ozone from A-C Transmission Lines."

We have reviewed your request and have determined that it addresses all of the criteria of a proper request under the FOIA, DOE, and BPA regulation that implements the FOIA at Title 10, Code of Federal Regulations, Part 1004.

Final response:
BPA is releasing the requested files in their entirety on the enclosed CD.

There are no fees associated with this request.

Pursuant to Department of Energy FOIA regulations at 10 C.F.R. § 1004.8, you may administratively appeal this response in writing within 30 calendar days. If you choose to appeal, please include the following:

(1) The nature of your appeal - denial of records, partial denial of records, adequacy of search, or denial of fee waiver;
(2) Any legal authorities relied upon to support the appeal; and

(3) A copy of the determination letter.

Clearly mark both your letter and envelope with the words "FOIA Appeal," and direct it to the following address:

Director, Office of Hearings and Appeals
Department of Energy
1000 Independence Avenue SW
Washington DC 20585-1615

Thank you for your interest in the Bonneville Power Administration. I appreciate the opportunity to assist you. If you have any questions about this letter, please contact Kim Winn, FOIA Public Liaison, at 503-230-5273.

Sincerely,

C. M. Frost
Freedom of Information Act Officer

Enclosure: CD

United States Department of the Interior

BONNEVILLE POWER ADMINISTRATION
BRANCH OF LABORATORIES

P.O. Box 491, VANCOUVER, WASHINGTON 98660

TECHNICAL REPORT NUMBER: ERJ-77-167

DATE: September 27, 1977

TITLE: Description of Equations and Computer Program for Predicting Audible Noise, Radio Interference, Television Interference, and Ozone from A-C Transmission Lines

AUTHOR: V. L. Chartier and R. H. Larson

VLC

ABSTRACT:

Presented in this report are the analytical expressions that are presently recommended by the Branch of Laboratories for predicting audible noise, RI, TVI, and ozone. This report also describes the computer program that can be used to make these calculations. The computer program is the result of combining several existing individual computer programs. These analytical expressions and the resultant computer program give state-of-the-art calculations. The Laboratories have ongoing R&D programs to collect data for better understanding of the corona processes. As this data is collected it will be compared with predictions from the computer, therefore, the analytical expressions will be improved as the new and better data shows that such improvements are needed.

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EMPIRICAL EXPRESSIONS FOR CALCULATING HIGH VOLTAGE TRANSMISSION CORONA PHENOMENA

BY

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Paper presented at the
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EMPIRICAL EXPRESSIONS FOR CALCULATING HIGH VOLTAGE TRANSMISSION CORONA PHENOMENA

Vern L. Chartier
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INTRODUCTION

The Bonneville Power Administration (BPA) engineers over the past 10 years have been developing empirical expressions for calculating corona phenomena associated with a-c and d-c high voltage transmission lines. The majority of these empirical expressions were developed from data obtained from BPA operating lines or test lines (The Dalles DC Test Line, Lyons 1200-kV Test Line) in conjunction with data that was in the technical literature, such as from the Apple Grove 750-kV Project and from Project UHV. Up until 1977, no single Division within BPA had the primary authority for developing these empirical expressions; therefore, such equations were being produced by System Engineering, Transmission Engineering, and the Laboratories. However, in 1977 the Chief Engineer assigned the responsibility for the development and maintenance of the empirical equations for calculating audible noise (AN), radio interference (RI), television interference (TVI), corona losses (CL), and ozone (Oz) to the Division of Laboratories.

As a result of this directive from the Chief Engineer, in 1977 Bob Larson and Vern Chartier produced a report that not only described the recommended equations for calculating corona phenomena for a-c lines, but also described a computer program written for the CDC 6600 that could make calculations for any a-c line. The initial computer program was limited to a-c lines. In addition, the line(s) could have no more than six phases and four overhead ground wires. That original computer program and the associated equations are described in BPA Division of Laboratories' Technical Report Number ERJ-77-167 [1].

Over the past 4 years the Laboratories has been updating that original computer program (called COMBINE) so that it could make all the corona phenomena calculations associated with both a-c and d-c lines. Subroutines for calculating electric and magnetic fields were also added. The original program was called COMBINE since it combined all the individual corona phenomena programs into one program and calculated the electric field at the surface of the conductor using a technique developed by Markt-Mengele [2, 3].

The purpose of this report is to describe the latest equations that are being used at BPA to make corona and field effect calculations. At this time, the program calculates the lateral profiles of AN, RI, TVI, electric field, and magnetic field. Lateral profile printouts of these sets of phenomena can be requested individually or collectively. If an individual printout is requested for audible noise and/or TVI, the noise contribution from each phase/pole plus the total is printed out. For RI, a frequency spectrum as a function of lateral distance is printed out. The individual printout for ozone gives both a vertical and a horizontal profile of O_3 concentration. The individual printouts for electric and magnetic fields give the maximum field and its electrical angle, and the maximum horizontal and vertical component and their appropriate electrical angles. A separate printout for corona loss can be requested which gives the total corona losses, the corona loss for each phase/pole as a function of rain intensity, and the average rain and average fair weather losses.

The user has the option of inputting values for conductor surface voltage gradients (previously calculated from some other source), or he may have the program compute them using the equation developed by Markt-Mengele [2, 3].

The user has the option of inputting and outputting values in either Metric or English units.

The program can handle a combination of 50 phases or poles and overhead ground wires. At this time the program cannot make calculations for a hybrid line (a-c and d-c lines in close proximity).

All the analytical expressions in this program are state-of-the-art. The Division of Laboratories makes an attempt to conduct measurement programs on BPA's existing transmission system and at the Lyons 1200-kV test facility to verify or update the analytical expressions. The Laboratories also tries to keep abreast of the R&D work being conducted all over the world on corona and field effects. Some of the data coming from other countries is sometimes used in conjunction with data from North America to update existing equations.

EFFECT OF ALTITUDE

Altitude has a very definite effect on the production of corona, as has been shown at the Leadville High Voltage Project operated by the Public Service Company of Colorado and Westinghouse in the 1950's [4, 5]. Obviously, the development of empirical expressions for the effect of altitude is difficult, since the only data in the literature is either from lines at sea level or the test line at Leadville (3400 m above sea level). Westinghouse engineers used the Leadville data to develop a term for correcting RI calculations made at sea level to

other altitudes [6]. Reference 6 also contains an Italian formula for the effect of altitude on RI. These two equations are compared in Figure 1. The agreement is quite good. The Westinghouse formula requires the user to know what the average relative air density is for each altitude, whereas the Italian formula only requires a knowledge of the altitude.

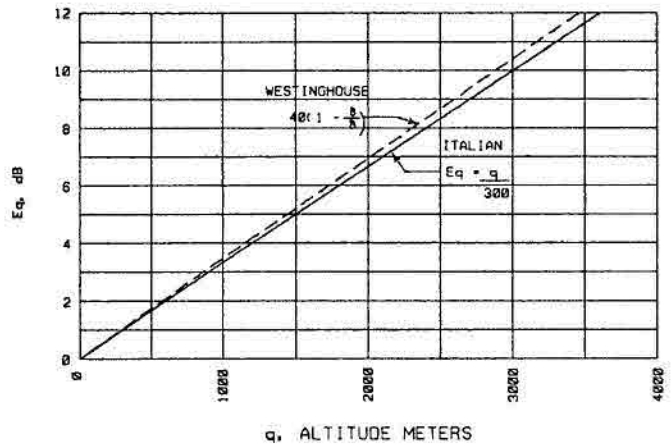


Figure 1: Effect of Altitude on Corona Phenomena

For calculating corona phenomena, the Italian correction term for altitude has been applied in the computer program for not only RI, but also for TVI, AN, and CL. It obviously has not been verified for either TVI or AN, and only partially verified for CL. However, it is better to have a correction term for all these corona phenomena rather than no term. After all, if RI and CL, which are the result of increased corona activity, increase with altitude so too must AN and TVI.

The use of this term for correcting CL needs further verification. A careful study of the Leadville [4] and Tidd [7] papers gives some indication that it might be valid for rain. However, the Leadville weather and the Tidd weather are very dissimilar. Foul weather at Leadville consists primarily of dry snow in the winter and very little rain, whereas foul weather at Tidd consists of mostly rain and wet snow; even the dry snow at Tidd is much wetter than Leadville snow. Heavy snow seems to produce higher corona losses than heavy rain or wet snow. This data indicates that dry snow produces a different type of corona (possibly ultra-corona) which may produce different levels of AN, RI, and TVI than either rain or wet snow.

Therefore, at this time, calculations using this altitude correction for determining corona loss should be made with a great deal of caution, especially for snowy weather.

AUDIBLE NOISE

The method of calculating A-weighted AN for a-c and d-c lines is based upon empirical expressions developed by V. L. Chartier and R. D. Stearns. Those equations and how they were developed are thoroughly described in an IEEE paper [8].

The equation for calculating the AN during rainy weather for each phase of an a-c line is:

$$SLA = -170.46 + 120 \log E + 55 \log deq - 11.4 \log D$$

where:

E = average maximum surface gradient kVrms/cm
deq = equivalent diameter of the bundle from an AN standpoint
deq = d for $n < 3$
= $(0.58d)n^{0.48}$ for $n \geq 3$
d = subconductor diameter, mm
n = number of subconductors in the bundle
D = radial distance between conductor and microphone, m

The formula for calculating the L_{50} A-weighted AN per positive pole for fair weather (the negative pole produces negligible AN) is:

$$SLA = -133.4 + 86 \log E + 40 \log deq - 11.4 \log D$$

deq = d for n = 1,2
= $(0.66d)\, n^{0.64}$ $n > 2$

The equations calculate the L_{50} rainy weather AN for a-c lines and the L_{50} fair weather AN for d-c lines. The L_{50} fair weather AN for a-c lines is calculated by subtracting 25 dB from the L_{50} rainy weather AN. The L_5 AN for rain for a-c lines is calculated by adding 3.5 dB to the L_{50} rainy weather AN.

For d-c lines, the L_5 fair weather AN is calculated by adding 3.5 dB to the L_{50} fair weather AN, whereas the L_{50} AN during rainy weather is calculated by subtracting 6 dB from the L_{50} fair weather AN. Only the positive pole produces measurable AN for d-c lines; therefore, -999.9 is printed out for the negative pole.

For the effect of altitude, the previously discussed term

$$AN = \frac{ALTIT}{300}$$

is used. However, its use below 300 m is not recommended since the data used to develop the empirical formulas was taken at altitudes primarily between 0 and 300 m. There has been some question about how to use this term around 300 m. It is strongly recommended by the Laboratories that until further data is collected the equations be used just as they are written, but that 1 dB be added for each 300 m above sea level.

RADIO NOISE

The methods of calculating RI for both a-c and d-c lines over the frequency range of 100 KHz to 20 MHz has evolved over the last 10 years. There is no single reference which describes the equations that are used by BPA. Reference 9 describes the general a-c equation that is used in the AM broadcast band and at distances within 60 m of the outside phase of

Table I: Prediction Formulas - DC Lines

	Ref.	
BPA Reiner Gehrig	[10]	$E = 51 + 1.5(g - 20.9) + 10 \log \frac{n}{2} + 40 \log \frac{d}{4.577} - 33 \log \frac{f}{0.834} - 40 \log \frac{D}{13.6}$
BPA Capon	[11]	$E = 214 \log \frac{g}{14} - 278 \left[\log(\frac{g}{14})\right]^2 + 40 \log \frac{d}{2} - 27 \log \frac{f}{0.834} - 40 \log \frac{D}{30.5}$
BPA Gehrig	[12]	$E = 1.6\, g + 40 \log \frac{d}{2} - 40 \log \frac{D}{30.5}$
BPA Perry	[13]	$E = E_o + 80 \log \frac{g}{g_o} + 10 \log \frac{n}{n_o} + 40 \log \frac{d}{d_o} + 40 \log \frac{D_o}{D}$
Germany	[14]	$E = E_o + K^*(g-g_o) + 40 \log \frac{d}{d_o} + 20 \log \frac{1+f_o^2}{1+f^2} + 29.4 \log \frac{D_o}{D}$
IREQ	[15, 16]	$\Gamma = \Gamma_o + 1.71(g-g_o) + 40 \log \frac{d}{d_o} + 30.8 \frac{n}{n_o}$
Sweden	[17]	$E = E_o + 10 \log n + 20 \log r + 1.5(g-g_o) - 40 \log \frac{D}{D_o}$

the line. BPA engineers have developed several equations for calculating d-c RI as can be seen in Table I. The only difference between all these BPA d-c equations is the effect of conductor surface gradient on RI.

AC EQUATION

The RI/phase at a horizontal distance of 15 m from the phase is given by:

$$RI = 48.0 + 120 \log \frac{E}{17.56} + 40 \log \frac{d}{35.1} + 10\,(1-(\log(10f))^2) + \frac{q}{300} - C_1 + C_2$$

where:

- E = average maximum conductor surface gradient, kVrms/cm
- d = conductor diameter, mm
- f = frequency, MHz
- q = altitude, m

All the constants in this equation came from the Apple Grove A-line, where excellent long-term RI data was collected over several years [18]. The constants C_1 and C_2 adjust the RI calculated at 15 m to other lateral distances from the line. The equations for these terms are based upon the work of Pakala and Chartier [19]. C_1 is a constant for the reference line at the particular distance conductor height, antenna height, and frequency for which the RI is being calculated. Therefore, C_2 is based upon the input data. The difference between C_1 and C_2 is added to the RI/phase calculations at 15 m.

The values of C_1 and C_2 are derived fr the following equations:

$$C = 10 \log (DW^2 + ESU^2 + EIND^2)$$

where:

DW is the direct wave component
ESU is the surface wave component
EIND is the induction field component

$$DW = \frac{\lambda\ Hc}{2\pi D} = \frac{47.7\ Hc}{fD}$$

when: $D < \frac{(12)\ Hc\ Ha}{\lambda}$

where:

- Hc is height of conductors, m
- D is radial distance between conductors and antenna, m
- f is frequency, MHz
- λ is wavelength, m
- Ha is height of antenna, m

when $D > \frac{12\ Hc\ Ha}{\lambda}$

$$DW = \frac{(47.7\ Hc)}{(f\ D)} \cdot \frac{(12\ Hc\ Ha)}{\lambda(D)} = \frac{1.908\ (Hc)^2\ Ha}{D^2}$$

$$ESU = \frac{f(\rho)\,Hc}{KD}$$

where:

$f(\rho)$ is Van de Pol's empirical relationship for the surface wave

$$K = \frac{2\pi}{\lambda}$$

$$f(\rho) = \frac{2 + 0.3\rho}{2 + \rho + 0.6\rho^2}$$

$$\rho = \frac{52.5D}{\delta\lambda^2}$$

δ = ground conductivity, m mho/m

$$EIND = \frac{Hc}{(KD)^2}$$

The reference parameters for calculating C_1

$$DW_1 = \frac{(47.75)(13.7)}{f(21.0)} = \frac{31.2}{f}$$

$$EIND_1 = \frac{13.7}{\left(\frac{2\pi fD}{300}\right)^2} = \frac{70.5}{f^2}$$

$$\rho_1 = \frac{(52.5)(21.0)}{4(\lambda)^2} = \frac{276.16}{\lambda^2}$$

$$f(\rho)_1 = \frac{2 + 0.3\rho_1}{2 + \rho_1 + 0.6\rho_1^2}$$

$$ESU_1 = f(\rho)_1 \cdot \frac{31.1}{f}$$

DC EQUATION

The RI/positive pole at a horizontal distance of 15 m from the positive pole is given by:

$$RI = 60.5 + 86 \log \frac{E}{27.5} + 40 \log \frac{d}{46.2} + 10(1-(\log(10f)^2) + \frac{q}{300} - C_1 + C_2$$

This equation calculates the average fair weather. All the constants in this equation come from the most recent RI tests at The Dalles d-c test site [20].

Data from IREQ [16] suggests that for d-c lines RI during average rain conditions is 3 dB less than average fair weather levels; whereas heavy rain RI is 6 dB less.

TELEVISION INTERFERENCE

The method for calculating TVI for a-c lines during rainy weather is based upon an equation developed by V. L. Chartier. The empirical terms used for calculating the propagation of TVI were developed from data in References 21 and 22.

The per phase TVI level in dB μV/m is given by:

$$TVI = 10.0 + 120 \log E/16.3 + 30.0 \log (D/30.4) + 20 \log (75.0/f) + C$$

where:

E = Conductor surface voltage gradient, kVrms/cm

D = Diameter of a subconductor in the bundle, mm

f = Frequency at which TVI is to be calculated

The constants in this equation come from a 345-kV line in New York where excellent TVI during steady rain was obtained [22]. Measurements of TVI from BPA lines have agreed quite well with calculated levels using this equation.

C is the correction factor to calculate the TVI at the radial distance from each phase. It can be determined from the Pakala-Chartier paper. C can also be determined by considering the four distinct cases shown in Table II.

No significant TVI has ever been measured from d-c lines during fair or foul weather. As a result, no attempt has been made to develop equations for calculating TVI from d-c lines.

CORONA LOSS

There are a number of methods that exist for calculating corona losses for both a-c and d-c lines. Most of these methods are not very easy to understand or use; therefore, in the Laboratories we decided to develop empirical equations similar to the equations for other corona phenomena [23].

AC LINES

The CL/phase in dB above 1 w/m is calculated using the following equation:

$$CL = 14.2 + 65 \log \frac{E}{18.8} + 40 \log \frac{d}{35.1} + K_1 \log \frac{n}{4} + K_2 + \frac{q}{300}$$

where:

n = number of subconductors

K_1 = 13 for $n < 4$
= 19 for $n > 4$

K_2 is a term that adjusts corona loss for rain intensity.

$$K_2 = 10 \log \frac{I}{1.676} \quad \text{for } I < 3.6$$

$$= 3.3 + 3.5 \log \frac{I}{3.6} \quad \text{for } I > 3.6$$

To calculate the losses in w/m or kW/km, the antilog of CL must be taken or:

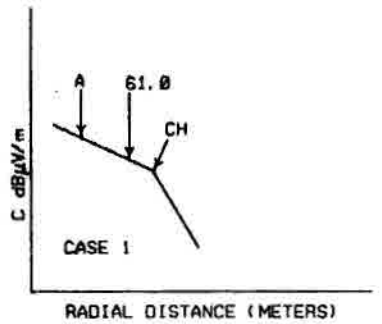
Table II

CASE 1: Do < CH
A < CH

Both the reference point and the measuring point lie on the 20 dB/decade slope of the curve.

The value of C is therefore determined by:

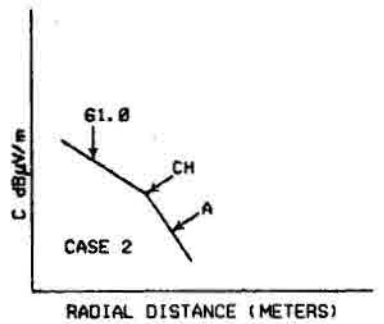
$$C = 20 \log_{10}(Do/A)$$



CASE 2: Do < CH
A > CH

If Do < CH and A > CH, we must move from the reference point down to the measuring point. Therefore:

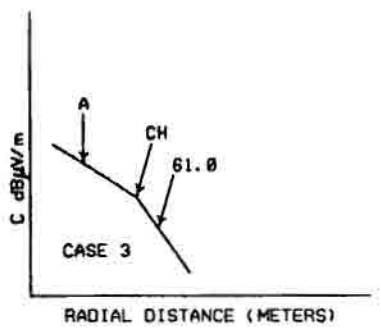
$$C = 20.0 \log_{10}(Do/CH) + 40.0 \log_{10}(CH/A)$$



CASE 3: Do > CH
A < CH

In this case we must move up from the reference point to the measuring point.

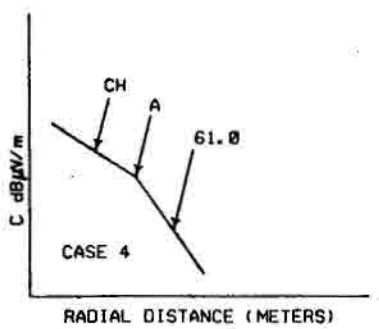
$$C = 20.0 \log_{10}(CH/A) + 40.0 \log_{10}(Do/CH)$$



CASE 4: 61 > CH
A > CH

In this case both points lie on the 40 dB/decade
portion of the curve. Therefore:

$$C = 40.0 \log_{10}(Do/A)$$



$$CL\ (W/m) = \text{antilog}\ \frac{CL(dB\ w/m)}{10}$$

The total losses for a line, of course, are:

$$CL\ (Total) = \quad CL(i)\ \ w/m$$

To calculate the average levels during rainy weather, the computer program assumes an average rain intensity of 1.676 mm/hr (this, of course, will vary from region to region). To calculate the average fair weather losses, the program subtracts 17 dB from the calculated average rainy weather losses. This difference of 17 dB was obtained from the Apple Grove test data [18] where carefully controlled fair weather measurements were made.

DC LINES

IREQ has conducted the most extensive corona loss measurements in all kinds of fair, rainy, and snowy weather. Consequently, until a better analysis of all the available corona loss data can be conducted, the Division of Laboratories has adopted the IREQ corona loss formula [16]. We have modified that formula so it calculates the average corona loss for each pole in rain, which assumes the corona losses are the same for the negative and positive poles of a d-c bipole line.

$$CL = 16.9 + 0.73\ (E - 25) + 20 \log \frac{d}{40.7} + 8 \log \frac{n}{6} + K_2 + q/300 - 3.0$$

To obtain average fair weather corona loss, 5 dB is subtracted from the average rainy weather calculation. At this time, we are assuming that the change in corona loss on d-c lines as a function of rain intensity is the same as for a-c lines; therefore, K_2 in the d-c formula is the same as for the a c formula.

OZONE CONCENTRATION

The method of calculating theoretical estimates of ozone concentrations is based on a method developed by V. L. Chartier and J. F. Roach [24].

For the case of a wind normal to the line, the lateral profile is estimated by (MKS units):

$$C(X,Z) = \sum_{i=1}^{3} \frac{\overline{Si}}{U \sigma_z \sqrt{2\pi}} \left\{ \exp\left[-\frac{(Z-H)^2}{2\sigma_z^2} \right] + \exp\left[-\frac{(Z+H)^2}{2\sigma_z^2} \right] \right\}$$

Where:

- Si is the source strength of the i-th line
- U is the wind speed
- H is the average height of the line above ground
- Z is the ozone sensor height
- σ_z is the spreading coefficient in the Z direction

The spreading coefficient is approximated by (MKS units):

$$z = .0315\ [23/U + 4.75(100/H)^{.25}]\ (X-X_i)^{.86}$$

Where X_i is the X coordinate of the i-th line source.

The source strength S_i for a-c lines is given by:

$$S_i = 1.260 \times 10^{-7}\ (P_i)(G_i)^2$$

and for d-c lines, it is:

$$S_i = 1.260 \times 10^{-9}\ P_i$$

for the negative pole, and:

$$S_i = 0.380 \times 10^{-9}\ P_i$$

for the positive pole.

DISCUSSION

1. Effect of altitude on corona phenomena is based upon radio noise and corona loss data obtained at Leadville, Colorado, in the 1950's.

   It is obvious that AN data is especially needed at higher altitudes, and it would be desirable to obtain additional RI and TVI data at higher altitudes. A test station will be installed on the Garrison-Hot Springs double-circuit 500-kV lines at an altitude of about 1800 m, which will provide some of this additional data.

2. The empirical expressions for calculating corona losses are primarily developed from rain data on both a-c and d-c lines. There is some indication that corona losses may be higher during dry snow conditions than during rainy weather. Dry snow being a sharp pointed object may be going into a form of ultra-corona which is known to be very lossy. The Leadville and other data needs to be examined in detail to determine if an additional correction factor for dry snow should be developed and added to existing CL formulas.

3. Most of the better radio noise formulas give about the same calculations for RI at the reference distance of 15 m from the outer phase. However, the agreement falls apart when a comparison of calculated lateral profiles is made. An example of this disagreement can be seen in Figure 2 where a comparison is shown between the calculated RI levels using the BPA empirical formula, and the General Electric analytical formula for the 500-kV base case delta-configurated line shown in Figure 5.4.22 of the "Red Book." Also shown on this curve is a calculated lateral profile, assuming the 1 MHz field produced by corona would have the same lateral profile as the 60 Hz field. Many analytical approaches have used this assumption for making RI calculations.

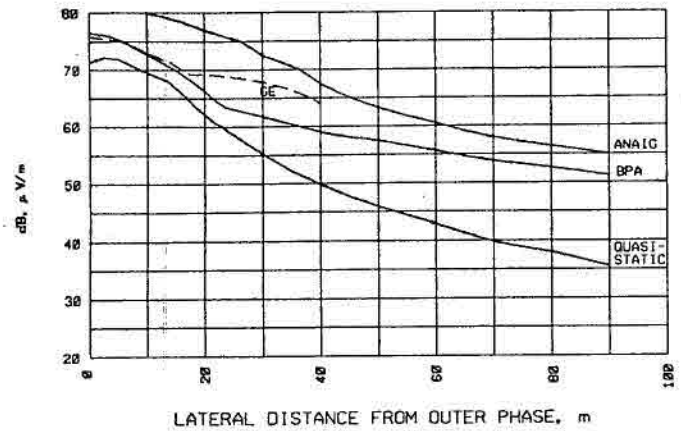


Figure 2: Comparison of Shapes of Radio Noise LateralAttenuation Profiles at 1 MHz

4. The difference between fair weather and foul weather AN is assumed to be 25 dB based upon data obtained on the Marion-Alvey and Marion-Lane 500-kV lines. Data from other lines in and outside of BPA territory indicates that this difference is a function of conductor surface gradient and possibly other line parameters. Therefore, additional data is needed to verify this assumption.

5. The formula for calculating TVI for a-c lines is quite similar to the RI formula, and like the RI formula, it assumes the TVI is primarily generated by conductor corona. Some data from the Apple Grove 750-kV project and the Lyons 1200-kV test facility indicate that TVI is independent of conductor configuration. This data suggests the primary source of the TVI might be the corona off the insulators or the tower hardware where the electric fields are stronger because of the proximity of the tower.

REFERENCES

1. V. L. Chartier and R. H. Larson. "Description of Equations and Computer Program for Predicting Audible Noise, Radio Interference, Television Interference, and Ozone from AC Transmission Lines." Bonneville Power Administration, Division of Laboratories Technical Report No. ERJ-77 1671.

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V. L. Chartier was born in Fort Morgan, Colorado, on February 14, 1939. He received B.S. degrees in Electrical Engineering and Business from the University of Colorado in 1963. From 1963 to 1975 he was with the Advanced Systems Technology Department of the Westinghouse Electric Corporation, where he was engineer-in-charge of the Apple Grove 750-kV Project and was a principal consultant to the utility industry on the effects of corona and electric fields of high voltage transmission lines. In 1975 he joined the Bonneville Power Administration's Division of Laboratories, where he has been assoicated with the Lyons 1200-kV Project and other high-voltage projects. He is presently BPA's Chief High Voltage Phenomena Engineer.

Mr. Chartier is a member of the USNC of IEC; Technical Advisior to the USNC of IEC on matters pertaining to CISPR Subcommittee C on High-Voltage Lines and Traction Systems; past Chairman of the IEEE/PES Corona and Field Effects Subcommittee; past member of the Board of Directors of the IEEE Electromagnetic Compatibility Society; Secretary of IEEE/PES Transmission and Distribution Committee; member of ANSI C63 Committee (Radio Electrical Coordination); Chairman of Subcommittee 4 (High Voltage Apparatus and Power Lines) of ANSI C63· Expert Advisor to CIGRE Study Committee No. 36 (Interference); member of CIGRE; and member of the Acoustical Society of America.

1. INTRODUCTION

This computer program computes lateral profiles of audible noise, radio interference (RI), television interference (TVI), and ozone concentration. Lateral profile printouts of these sets of phenomena can be requested individually or collectively. If an individual printout is requested, audible noise, RI, or TVI will be presented on a noise per phase arrangement. A vertical as well as a horizontal profile of ozone concentration is available upon request.

Subroutines for audible noise, RI,[1-3] and TVI[2,4,5] are modified versions of programs originally developed and coded by V. L. Chartier of BPA. The subroutine for calculation of ozone production is a modified version of a program written by Dan Bracken of BPA based on research by V. L. Chartier and J. F. Roach of Westinghouse.[6] A subroutine for calculation of the conductor surface voltage gradient was based on Mangoldt's equation[1,7] and was coded by R. H. Larson of BPA. Within the ozone subroutine is an empirical equation for calculating corona losses which was taken from a paper by T. Sugimoto of the Shiobara Test Project[8] and coded by R. H. Larson.

The user has the option of inputting values for conductor surface voltage gradients (previously calculated from some other source)or he may have the program compute them using the equation developed by Mangoldt.

The user has the option of inputting and outputting values in either Metric or English units.

The program has a capability of performing calculations on either single or double circuit transmission line configurations where a maximum of four overhead ground wires are in existence.

It is possible to process multiple problems sequentially by stacking the data cards for each study sequentially.

This computer program is the result of combining existing programs for calculating these corona phenomena. All the analytical expressions are state-of-the-art. The Laboratories has on-going R&D projects for verifying and improving the accuracy of these analytical techniques; therefore, reports will be issued as new analytical expressions are developed.

2. AUDIBLE NOISE

The method of calculating A-weighted audible noise is based on an empirical equation developed by V. L. Chartier of BPA.

The audible noise per phase is given by:

$$120.0 \log_{10}(E) + 55.0 \log_{10}(Deq) - 11.4 \log_{10}(R) - 170.5$$

where: E = maximum conductor surface voltage gradient, kVrms/cm

$$Deq = .589(D) * N^{(.482)} \text{ for } N \geq 4$$
$$= D \text{ if } N < 4$$

N = Number of conductors in the bundle
D = Diameter of a subconductor in the bundle, mm
R = Radial distance from bundle center to calculating point, m

The total audible noise is the sum of the contribution of each of the three phases calculated in decibels.

3. RADIO NOISE

The method of calculating RI is based on an empirical equation developed by W. E. Pakala and V. L. Chartier,[1-3]

The RI/phase in dB above one μV/m is given by:

for $R \leq CH$:

$$RI = 48.0 + 3.5\,(E-17.5) + 30.0 \log_{10}(D/35.1) + 20.0 \log_{10}(30.7 * Y/R^2) + 10.0(1-f)$$

and for $R > CH$:

$$RI = 48.0 + 3.5\,(E-17.5) + 30.0 \log_{10}(D/35.1) + 20.0 \log_{10}(30.7 * Y/B) + 20.0 \log_{10}(CH/R) + 10.0\,(1-f)$$

where:

CH = $\lambda/2\pi$ where λ is in m
E = Maximum conductor surface gradient, kVrms/cm
D = Diameter of subconductor in bundle, mm
Y = Midspan height of bundle, m
B = $(\lambda/2\pi)^2$
R = Radial distance from transmission line to calculating point, m
f = Frequency at which RI is to be calculated, MHz

This equation is valid for frequencies between 0.2 and 1.6 MHz.

4. TVI

The method for calculating television interference is based on an equation developed by V. L. Chartier.[2,4,5] The per phase TVI level in dB above one μV/m is given by:

$$TVI = 10.0 + 3.5(E-16.3) + 30.0 \log_{10}(D/30.4) + 20 \log_{10}(75.0/f) + C$$

where:

E = Conductor surface voltage gradient, kVrms/cm
D = Diameter of a subconductor in the bundle, mm
f = Frequency at which TVI is to be calculated

There are four distinct cases which need to be considered to determine the value of C:

1. $61.0 < CH$, $A < CH$
2. $61.0 < CH$, $A > CH$
3. $61.0 > CH$, $A < CH$
4. $61.0 > CH$, $A > CH$

where:

A is the radial distance from the conductor to the measuring point.

61.0 is the reference radial distance for which the empirical formula was developed.

CH is the "changeover" distance given by for formula: $CH = \frac{(12.0)(HA)(HC)(f)}{\lambda}$

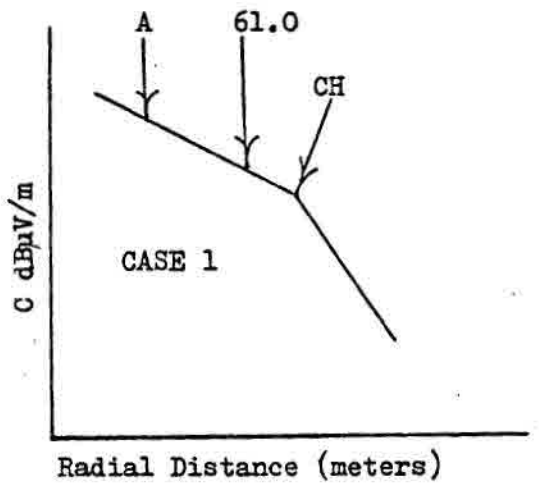
λ = Wavelength
f = TVI measuring frequency
HA = Antenna height
HC = Conductor height

CASE 1: $61.0 < CH$
$A < CH$

Both the reference point and the measuring point lie on the 20 dB/decade slope of the curve.

The value of C is therefore determined by:

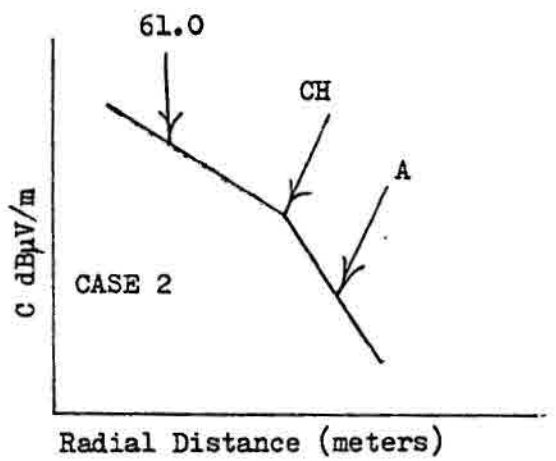
$$C = 20 \log_{10}(61.0/A)$$



CASE 2: $61.0 < CH$
$A > CH$

If $61.0 < CH$ and $A > CH$, we must move from the reference point down to the measuring point, therefore:

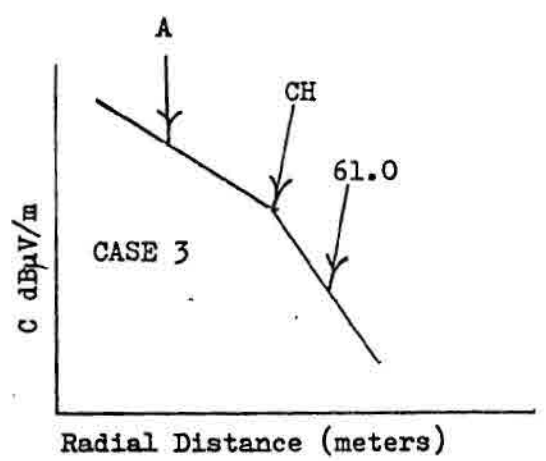
$$C = 20.0 \log_{10}(61.0/CH) + 40.0 \log_{10}(CH/A)$$



CASE 3: $61.0 > CH$
$A < CH$

In this case we must move up from the reference point to the measuring point.

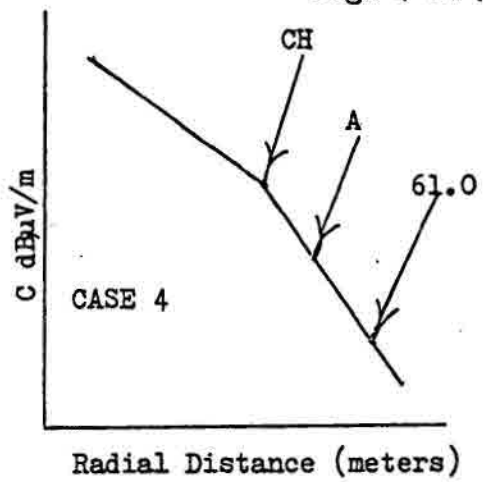
$$C = 20.0 \log_{10}(CH/A) + 40.0 \log_{10}(61.0/CH)$$



CASE 4: $61 > CH$
$A > CH$

In this case both points lie on the 40 dB/decade portion of the curve, therefore:

$$C = 40.0 \log_{10}(61.0/A)$$



5. OZONE CONCENTRATION

The method of calculating theoretical estimates of ozone concentrations is based on a method developed by V. L. Chartier and J. F. Roach.[6]

For the case of a wind normal to the line, the lateral profile is estimated by (MKS units)

$$C(X,Z) \cong \sum_{i=1}^{3} \frac{\overline{S_i}}{U\sigma_Z\sqrt{2\pi}} \left\{ \exp\left[-\frac{(Z-H)^2}{2\sigma_Z^2}\right] + \exp\left[-\frac{(Z+H)^2}{2\sigma_Z^2}\right] \right\}$$

where S_i is the source strength of the i-th line, U is the wind speed, H is the average height of the line above ground, Z is the ozone sensor height, and σ_Z is the spreading coefficient in the Z direction.

0 5 10 15

The spreading coefficient is approximated by (MKS units):

$$\sigma_Z = .0315 \left[23/U + 4.75(100/H)^{.25}\right] \quad (X-X_i)^{.86}$$

where X_i is the X coordinate of the i-th line source.

The source strength S_i is given by:

$$S_i = 1.260 \times 10^{-7} (P_i)(G_i)^2$$

where P_i, the corona loss per line source, is given by an empirical equation developed by Sugimoto of the Shiobara test station.[8]

$$P_i = \frac{.021\, r^2\, N\, e^{0.27E}}{\frac{123.0}{R}\, e^{-0.22E} + 1.0} \quad \text{kW/km}$$

where:

r = Radius of the subconductor
N = Number of conductors
E = Maximum potential gradient at the conductor surface (kV/cm)
R = Precipitation rate (mm/hr)

G_i, the maximum surface gradient factor per phase, is given by:

$$G_i = \frac{E_i}{kV(rms)}$$

6. CALCULATION OF CONDUCTOR SURFACE GRADIENT

The formula for calculating the gradient per phase was developed by Mangoldt.[7]

$$E = (18.0 \times 10^6) \quad Q \left[\frac{1 + \frac{K_2}{(s/r)}}{Nr} \right] \quad \text{kVrms/cm}$$

where: $K_2 = 2(N-1)\sin \frac{\pi}{N}$

s = Subconductor spacing
r = Radius of a subconductor
N = Number of subconductors in bundle
Q = Total Charge on the bundle

7. INPUT SPECIFICATIONS

CARDS 1, 2

BCD heading cards used for study identification
72 columns of each are used
Note that the first column is not used

Columns	Field Contents	Format
2-73	Any BCD alphanumeric heading for study identification	12A6

CARD 3

Contains option flags and other miscellaneous input data

Columns	Field Contents	Format
8	Units option flag Metric units = 0 or blank English units = 1	I1

CARD 3 con't

Columns	Field Contents	Format
16	Gradient option flag 1 = gradient to be inputted 0 = gradient will be computed by the program	I1
24	Number of phases (3 or 6)	I1
31-32	Total number of conductors (number of phases + number of earth wires)	I2
33-40	Line-line voltage in kV/rms	F8.0
41-48	Wind velocity in m/s or mi/hr. This is used in calculating spreading coefficients in the ozone subroutine	F8.0
49-56	Rain rate in mm/hr or in/hr (this is used in computing corona losses in the ozone subroutine)	F8.0

CARD 4

Contains flags specifying which type of interference is to be computed: AN, RI, TVI, ozone, or a combination thereof.

Columns	Field Contents	Format
1-4	If the combined printout of all four types of interference is desired, type in the word "COMB" in this field.	A4
7-8	For specifying individual printouts.	A2
11-12	In any of these fields type in the correspond-	A2
15-16	ing two character name of the type of indi-	A2
19-20	visual printout desired	A2
	AN = audible noise RI = radio noise TV = television interference OZ = ozone concentrations Any or all of these names may be used in any order	

CARD 5

Antenna (or sensor) heights and standard frequency specification card

Columns	Field Contents	Format
1-8	Vertical height of audible noise microphone	F8.0

CARD 5 con't

Columns	Field Contents	Format
9-16	Vertical height of RI antenna	F8.0
17-24	Vertical height of TVI antenna	F8.0
25-32	Vertical height of ozone sensor	F8.0
33-40	Frequency at which RI values are to be calculated. (BPA uses .834 MHz, IEEE uses 1.0 MHz)	F8.0
41-48	Frequency at which TVI values are to be calculated. (usually around 75 MHz)	F8.0

CARDS 6 to (number of conductors +5)

Phase information cards. There must be one for each phase (and one for each earth wire if gradients are to be calculated).

Columns	Field Contents	Format
1-8	An eight character alphanumeric identification name for each conductor group	A8
9-16	Horizontal distance of conductor bundle center from reference axis (meters or feet)	F8.0
17-24	Bundle center midspan height (meters or feet)	F8.0
25-32	Number of subconductors in the group or bundle	F8.0
33-40	Subconductor diameter (mm or in)	F8.0
41-48	Bundle subconductor spacing (cm or in)	F8.0
49-56	Line to neutral voltage kV(rms) for the bundle	F8.0
57-64	Electrical phase angle in degrees of the conductor voltage with respect to any arbitrary synchronous reference	F8.0
65-72	The value of the conductor gradient is entered in this field (only if col. 16 on CARD 3 is a 1, i.e., the user would rather input his own value for the gradient)	F8.0

Lateral Profile Distance CARDS

After the phase information cards come the cards specifying the lateral distances from the reference axis at which points the calculations are to be made. Several of these cards can be used as desired if varying distance increments are preferred over different distance ranges (a maximum of 50 points can be used)

Columns	Field Contents	Format
7-8	The number of points corresponding to the starting distance and the distance increment designated respectively by the next two data fields	I2
9-16	Location of the horizontal starting point for a set of calculating points	F8.0
17-24	The distance increment for a set of calculating points	F8.0

Blank CARD

Each case study should be followed by a blank card.

8. DATA ORDER

The order of the data cards is the same as they are listed in the input specifications section with heading cards coming first and distance card(s) last followed by a blank card.

A blank card indicates the end of a study. If there is another sequential study to follow, its heading cards will immediately follow the blank card.

When there are no more studies to be processed, a card with an asterisk(*) punched in column 1 should follow the blank card of the last data set.

An example of a listing of input data for two studies run consecutively is shown in Table I.

Requested by _____ Ext No. _____ Job code _____

BONNEVILLE POWER ADMINISTRATION
FORTRAN CODING FORM

Project _____ Sheet _____ of _____

Statement No.	CONT	STATEMENT	Identification
		OREGON CITY - KEELER 3-3.089 CM AAAC	
		10.21 M PHASE SPACING, 15.24 M COND HT	
		0 0 3 3 525.0 .224 25.4	
		COMB AN RI TV OZ	
		1.5 1.0 3.0 0.0 0.834 75.0	
		PHASE A -10.21 15.24 3.0 30.89 45.72 303.11 0.0	
		PHASE B 0.0 15.24 3.0 30.89 45.72 303.11 -120.0	
		PHASE C 10.21 15.24 3.0 30.89 45.72 303.11 120.0	
		ZO 0.0 5.0	
		BLANK CARD	
		LINE CONFIGURATION #L - SURVEY ON METHODS OF CALCULATING TRANSMISSION	
		LINE CONDUCTOR SURFACE VOLTAGE GRADIENTS	
		0 0 3 3 345.0 .224 50.8	
		COMB AN OZ	
		1.5 1.0 3.0 0.0 1.000 75.0	
		PHASE A -7.92 11.18	
		PHASE B 0.0 11.18	
		PHASE C 7.92 11.18	
		EARTH 1 -5.0 22.0	
		EARTH 2 5.0 22.0	
		21 0.0 5.0	
		10 110.0 10.0	
		BLANK CARD	
		*	

9. DATA OUTPUT

An example of the data output for Case 1 shown in Table I is shown in the following pages.

AUDIBLE NOISE CALCULATIONS EQUIVALENT DIAMETER FORMULA

OREGON CITY - KEELER 3-3.089 CM AAAC
10.21 M PHASE SPACING, 15.24 M COND HT

	DIST. FROM CENTER OF TOWER (METERS)	HEIGHT (METERS)	MAXIMUM GRADIENT (KV/CM)	SUBCON. DIAM. (MM)	NO. OF SUBCON.
PHASE A	-10.21	15.24	16.46	30.89	3
PHASE B	0.00	15.24	17.85	30.39	3
PHASE C	10.21	15.24	16.46	30.89	3

MICROPHONE HT.= 1.5 METERS

DIST FROM CENTERLINE (METERS)	TOTALS (RAIN) L5 (DBA)	L50 (DBA)	PHASE A L50 (DBA)	PHASE B L50 (DBA)	PHASE C L50 (DBA)
0.0	54.2	50.7	43.4	48.7	43.4
5.0	54.0	50.5	42.5	48.4	44.1
10.0	53.5	50.0	41.6	47.6	44.4
15.0	52.8	49.3	40.8	46.3	44.2
20.0	52.0	48.5	40.1	45.9	43.4
25.0	51.2	47.7	39.4	45.1	42.5
30.0	50.5	47.0	38.9	44.4	41.7
35.0	49.3	46.3	38.3	43.7	40.9
40.0	49.2	45.7	37.8	43.1	40.1
45.0	48.6	45.1	37.4	42.6	39.5
50.0	48.1	44.6	37.0	42.1	38.9
55.0	47.7	44.2	36.6	41.7	38.4
60.0	47.3	43.8	36.3	41.3	37.9
65.0	46.9	43.4	35.9	40.9	37.4
70.0	46.5	43.0	35.6	40.5	37.0
75.0	46.2	42.7	35.3	40.2	36.7
80.0	45.9	42.4	35.1	39.9	36.3
85.0	45.6	42.1	34.8	39.6	36.0
90.0	45.3	41.8	34.6	39.3	35.7
95.0	45.0	41.5	34.3	39.1	35.4

RADIO NOISE CALCULATIONS WESTINGHOUSE SIMPLE FORMULA

OREGON CITY - KEELER 3-3.089 CM AAAC
10.21 M PHASE SPACING, 15.24 M COND HT

	DIST. FROM CENTER OF TOWER (METERS)	HEIGHT (METERS)	MAXIMUM GRADIENT (KV/CM)	SUBCON. DIAM. (MM)	NO. OF SUBCON.
PHASE A	-10.21	15.24	16.46	30.89	3
PHASE B	0.00	15.24	17.86	30.39	3
PHASE C	10.21	15.24	16.46	30.89	3

ANTENNA HT.= 1.0 METERS, FREQ.= .834 MHZ

DIST FROM CENTERLINE (METERS)	HEAVY RAIN (DB)	FAIR WEATHER (DB)	PHASE A RI (DB)	PHASE B RI (DB)	PHASE C RI (DB)
0.0	80.5	56.5	48.0	56.5	48.0
5.0	79.5	55.5	45.0	55.5	50.5
10.0	77.0	53.0	42.0	53.0	51.6
15.0	74.7	50.7	39.3	50.0	50.7
20.0	72.3	48.3	36.8	47.1	48.3
25.0	69.3	45.3	34.6	44.3	45.3
30.0	66.3	42.3	32.6	41.8	42.3
35.0	63.6	39.6	30.7	39.6	39.5
40.0	61.5	37.5	29.1	37.5	37.0
45.0	59.7	35.7	27.5	35.7	34.8
50.0	58.0	34.0	26.8	34.0	32.7
55.0	56.5	32.5	26.1	32.5	30.9
60.0	55.7	31.7	25.5	31.7	29.2
65.0	55.0	31.0	24.9	31.0	27.6
70.0	54.4	30.4	24.4	30.4	26.8
75.0	53.9	29.9	23.9	29.9	26.2
80.0	53.3	29.3	23.4	29.3	25.6
85.0	52.8	28.8	22.9	28.8	25.0
90.0	52.3	28.3	22.5	28.3	24.4
95.0	51.9	27.9	22.1	27.9	23.9

TVI CALCULATIONS, QP DETECTOR, STODDART NM30A METER

OREGON CITY - KEELER 3-3.089 CM AAAC
10.21 M PHASE SPACING,15.24 M COND HT

	DIST. FROM CENTER OF TOWER (METERS)	HEIGHT (METERS)	MAXIMUM GRADIENT (KV/CM)	SUBCON. DIAM. (MM)	NO. OF SUBCON.
PHASE A	-10.21	15.24	16.46	30.89	3
PHASE B	0.00	15.24	17.86	30.89	3
PHASE C	10.21	15.24	16.46	30.89	3

ANTENNA HT.= 3.0 METERS, FREQ.= 75.000 MHZ

DIST FROM CENTERLINE (METERS)	TOTALS (RAIN) QUASI-PEAK DBUV/M	PHASE A QP DBUV/M	PHASE B QP DBUV/M	PHASE C QP DBUV/M
0.0	29.6	22.4	29.6	22.4
5.0	29.0	20.7	29.0	24.0
10.0	27.4	19.0	27.4	24.7
15.0	25.6	17.5	25.6	24.1
20.0	24.0	16.2	24.0	22.6
25.0	22.5	15.0	22.5	20.8
30.0	21.2	14.0	21.2	19.1
35.0	20.0	13.1	20.0	17.6
40.0	19.0	12.2	19.0	16.3
45.0	18.0	11.4	18.0	15.1
50.0	17.1	10.7	17.1	14.1
55.0	16.4	10.0	15.4	13.1
60.0	15.6	9.4	15.6	12.3
65.0	15.0	8.8	15.0	11.5
70.0	14.3	8.3	14.3	10.8
75.0	13.8	7.8	13.8	10.1
80.0	13.2	7.3	13.2	9.5
85.0	12.7	6.8	12.7	8.9
90.0	12.2	6.4	12.2	8.3
95.0	11.8	6.0	11.8	7.8

OREGON CITY - KEELER 3-3.069 CM AAAC
16.21 M PHASE SPACING,15.24 M COND HT

X(1) = -10.2 METERS, Y(1) = 15.2 METERS, S(1) = 4.209E-09 KG/M/SEC. 16.461 11.328 3.000
X(2) = 0.0 METERS, Y(2) = 15.2 METERS, S(2) = 7.463E-09 KG/M/SEC. 17.862 17.057 3.000
X(3) = 10.2 METERS, Y(3) = 15.2 METERS, S(3) = 4.209E-09 KG/M/SEC. 16.461 11.328 3.000

RAIN = 25 MM/HR.

WIND VELOCITY = .224 METERS/SEC, S(MEAN) = 5.294E-09 KG/M/SEC.

OZONE CONCENTRATION IN PPHM

HEIGHT	LATERAL DISTANCE FROM CENTERLINE (METERS)										
	0	5	10	15	20	25	50	75	100	125	150
0	.0288	.0570	.0472	.0721	.0608	.0497	.0266	.0186	.0145	.0120	.0102
5	.0284	.0573	.0466	.0725	.0603	.0494	.0265	.0186	.0145	.0120	.0102
10	.0274	.0572	.0454	.0729	.0589	.0486	.0264	.0186	.0145	.0120	.0102
15	.0257	.0555	.0432	.0712	.0565	.0473	.0262	.0185	.0145	.0119	.0102
20	.0236	.0509	.0404	.0661	.0533	.0456	.0260	.0184	.0144	.0119	.0102
25	.0210	.0436	.0370	.0579	.0494	.0435	.0257	.0183	.0144	.0119	.0102
30	.0182	.0350	.0332	.0482	.0452	.0410	.0253	.0182	.0143	.0119	.0102
35	.0153	.0267	.0292	.0389	.0407	.0384	.0249	.0181	.0142	.0118	.0101
40	.0125	.0189	.0253	.0313	.0362	.0355	.0244	.0179	.0142	.0118	.0101
45	.0098	.0149	.0215	.0257	.0319	.0327	.0238	.0177	.0141	.0117	.0101
50	.0075	.0114	.0180	.0216	.0274	.0296	.0232	.0175	.0140	.0117	.0100

COMBINED OUTPUT OF AUDIBLE NOISE, RADIO NOISE, TVI, AND OZONE CONCENTRATION

OREGON CITY - KEELER 3-3.089 CM AAAC
10.21 M PHASE SPACING, 15.24 M COND HT

525 KV

	DIST. FROM CENTER OF TOWER (METERS)	HEIGHT (METERS)	MAXIMUM GRADIENT (KV/CM)	SUBCON. DIAM. (MM)	NO. OF SUBCON.	SUBCON SPACING (CM)	VOLTAGE L-N (KV)	PHASE ANGLE (DEGREES)	CORONA LOSSES (KW/KM)
PHASE A	-10.21	15.24	16.45	30.89	3	45.72	303.11	0.00	11.33
PHASE B	0.00	15.24	17.86	30.89	3	45.72	303.11	-120.00	17.06
PHASE C	10.21	15.24	16.46	30.89	3	45.72	303.11	120.00	11.33

AN MICROPHONE HT.= 1.5 M, RI ANT. HT.= 1.0 M, TV ANTENNA HT.= 3.0 M
RI FREQ= .834 MHZ, TV FREQ= 75.000 MHZ, WIND VEL.(O3)= .224 M/SEC

LATERAL DIST FROM CENTERLINE (METERS)	AUDIBLE NOISE TOTALS (RAIN) L5 DBA	L50 DBA	RADIO INTERFERENCE RAIN HEAVY DBUV/M	RAIN L50 DBUV/M	FAIR L50 DBUV/M	TVI TOTAL RAIN DBUV/M	OZONE FOR RAIN RATE OF 25.40 MM/HR AT 0 M LEVEL PPHM
0.0	54.2	50.7	80.5	73.5	56.5	29.6	.0288
5.0	54.0	50.5	79.5	72.5	55.5	29.0	.0570
10.0	53.5	50.0	77.0	70.0	53.0	27.4	.0472
15.0	52.8	49.3	74.7	67.7	50.7	25.6	.0721
20.0	52.0	48.5	72.3	65.3	48.3	24.0	.0608
25.0	51.2	47.7	69.3	62.3	45.3	22.5	.0497
30.0	50.5	47.0	66.3	59.3	42.3	21.2	.0420
35.0	49.8	46.3	63.6	56.6	39.6	20.0	.0365
40.0	49.2	45.7	61.5	54.5	37.5	19.0	.0324
45.0	48.6	45.1	59.7	52.7	35.7	18.0	.0292
50.0	48.1	44.6	58.0	51.0	34.0	17.1	.0266
55.0	47.7	44.2	56.5	49.5	32.5	16.4	.0244
60.0	47.3	43.8	55.7	48.7	31.7	15.6	.0226
65.0	46.9	43.4	55.0	48.0	31.0	15.0	.0211
70.0	46.5	43.0	54.4	47.4	30.4	14.3	.0198
75.0	46.2	42.7	53.9	46.9	29.9	13.8	.0186
80.0	45.9	42.4	53.3	46.3	29.3	13.2	.0176
85.0	45.6	42.1	52.8	45.8	28.8	12.7	.0167
90.0	45.3	41.8	52.3	45.3	28.3	12.2	.0159
95.0	45.0	41.5	51.9	44.9	27.9	11.8	.0152

10. FORTRAN LISTING

The following pages are the FORTRAN listing for the computer program.

```
      PROGRAM COMBINE(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON/AREA/NPH,FREQRI,FREQTV,X(10),Y(10),GRAD(10),DIAM(10),ANR(10
     1),          NCOMB,NPT,SD,DI,NPTF,TITLE(2,12),DIS(50),UNITS,
     2   FAZNUM(10)
      DIMENSION SPECTM(4),SLALS(50),SLALSC(50),TVMAX(50),RIFAIR(50)
     1   ,HRAIN(50),ARAIN(50),SUBSPC(10),V(10),PH(10),OZONE(50)
     2   ,F(6)
      INTEGER UNITS
   19 DO 50 L=1,2
      READ(5,22) COL1,(TITLE(L,K),K=1,12)
   22 FORMAT(A1,12A6)
      IF( COL1.EQ.1H*)GO TO 155
   50 CONTINUE
      READ(5,1000) UNITS,IGRAD,NPH,NC,VOLTLL,WIND,RAIN
 1000 FORMAT(7X,I1,7X,I1,7X,I1,6X,I2,F8.0,F8.0,F8.0)
      READ(5,15)COMB,(SPECTM(I),I=1,4)
   15 FORMAT(A4,4(2X,A2))
      NCOMB=0
      NPTF=0
      READ(5,34000)VERTAN,VERTRI,VERTTV,VERTOZ,FREQRI,FREQTV
C
C     SUBCONDUCTOR SPACING IN CM,  DIAM IN MM IF METRIC UNITS ARE USED
C
      DO 110 I=1,NC
      READ 36000,FAZNUM(I),X(I),Y(I),ANR(I),DIAM(I),SUBSPC(I),V(I),PH(I)
     1   ,GRAD(I)
      F(I) = 0.0
  110 CONTINUE
  501 READ(5,35000) NPT,       SD,DI
34000 FORMAT(6F8.0)
35000 FORMAT(6X,I2,2F8.0)
36000 FORMAT(A8,6F8.0)
      IF(NPT.EQ. 0) GO TO 630
      NPTI = NPTF
      NPTF = NPT + NPTI
      NPTI = NPTI +1
      DO 650 I = NPTI, NPTF
      DIS(I)=SD
      SD = SD + DI
  650 CONTINUE
      GO TO 501
C
  630 IF (UNITS.EQ. 1 ) GO TO 700
  625 CONTINUE
```

```
      IF (IGRAD.EQ. 1 ) GO TO 625
            CALL MANGO  (X,Y,DIAM,V,PH,  ANR,SUBSPC,GRAD,NC )
  625 CONTINUE
      DO 615 I=1,4
      IF( SPECTM(I).EQ.2HAN) CALL AN(SLALS,SLALSO,VERTAN)
      IF( SPECTM(I).EQ.2HRI) CALL RI(HRAIN,RIFAIR,VERTRI,ARAIN)
      IF( SPECTM(I).EQ.2HTV) CALL TVI(TVMAX ,VERTTV)
      IF( SPECTM(I).EQ.2HOZ)CALL OZ(WIND,RAIN,VOLTLL,OZONE,VERTOZ,P)
  615 CONTINUE
      IF( COMS.EQ. 4HCOMS )  GO TO 610
       GO TO 19
C
CONVERT ENGLISH TO METRIC
C
  700 VERTAN = VERTAN/3.28
      VERTRI = VERTRI/3.28
      VERTTV = VERTTV/3.28
      VERTOZ = VERTOZ/3.28
      WIND = WIND*.447
      RAIN = RAIN * 25.4
      DO 705 I = 1, NC
      X(I)=X(I)/3.28
      Y(I)=Y(I)/3.28
      SUBSPC(I)=SUBSPC(I)*2.54
      DIAM(I)=DIAM(I)*25.4
  705 CONTINUE
      DO 710 M=1,NRTF
  710 DIS(M) = DIS(M)/3.28
      GO TO 525
C
  800 NCOMS = 1
      CALL AN ( SLALS,SLALSO ,VERTAN)
      CALL RI ( HRAIN,RIFAIR,VERTRI,ARAIN)
      CALL TVI(        TVMAX   ,VERTTV)
      CALL OZ(WIND,RAIN,VOLTLL,OZONE,VERTOZ,P)
      PRINT 2000
 2000 FORMAT(1H1)
      PRINT 2002
 2002 FORMAT( * COMBINED OUTPUT OF AUDIBLE NOISE, RADIO NOISE, TVI*
     1   *, AND OZONE CONCENTRATION  *  /  )
      DO 20 L=1,2
   20 PRINT 2001,(TITLE(L,K),K=1,12)
 2001 FORMAT(1X,12A6)
      PRINT 2020,VOLTLL
 2020 FORMAT(1H0,F5* KV* )
```

```
      PRINT 2003
 2003 FORMAT ( *  * )
      PRINT 10008
      PRINT 10007
      IF(UNITS.EQ. 1) PRINT 10010
      IF(UNITS.EQ. 1) GO TO 800
      PRINT 10009
10009 FORMAT(15X,*(METERS)*4X*(METERS)*2X*(KV/CM)*3X*(MM)*15X
     1  *(CM)        (KV)   (DEGREES)   (KW/KM)   *  /  )
10010 FORMAT(15X,* (FEET) *4X* (FEET) *2X*(KV/CM)*3X*(IN)*15X
     1  *(IN)        (KV)   (DEGREES)   (KW/MI)   *  /  )
10008 FORMAT(14X,*DIST. FROM*,13X,*MAXIMUM  SUBCON.  NO. OF    SUBCON*
     1  *   VOLTAGE   PHASE    CORONA   *  )
10007  FORMAT(11X,*CENTER OF TOWER  HEIGHT  GRADIENT   DIAM.   SUBCON.*
     1   *   SPACING    L-N     ANGLE    LOSSES   *  )
10006 FORMAT(1X ,              A8        ,4X, F9.2,6X,F6.2,F9.2,F9.2,5X,F2
     1  ,4X,F8.2  ,2X,F8.2  ,1X,F8.2,1X,F8.2)
  300 DO 35 I = 1,NC
      WRITE (6,10006) FAZNUM(I),X(I),Y(I),GRAD(I),DIAM(I),ANR(I)
     1  ,SUBSPC(I),V(I),PH(I),P(I)
   35 CONTINUE
      IF(UNITS.EQ. 1) PRINT 10011,VERTAN,VERTRI,VERTTV,FREQRI,FREQTV
     1  ,WIND
      IF(UNITS.EQ. 1) GO TO 350
      PRINT 10001,VERTAN,VERTRI,VERTTV,FREQRI,FREQTV,WIND
10001 FORMAT(1H0,*AN MICROPHONE HT.=*F5.1* M,  RI ANT. HT.=*F5.1
     1  * M,  TV ANTENNA HT.=*F5.1* M *  /
     2 * RI FREQ=*F7.3* MHZ,*3X*TV FREQ= * F7.3* MHZ,    *
     3 *WIND VEL.(G3)=* F6.3* M/SEC* / )
10011 FORMAT(1H0,*AN MICROPHONE HT.=*F5.1* FT, RI ANT. HT.=*F5.1
     1  * FT, TV ANTENNA HT.=*F5.1* FT*  /
     2 * RI FREQ=*F7.3* MHZ,*3X*TV FREQ= * F7.3* MHZ,*
     1*   WIND VEL.(G3) = * F6.3* MPH * / )
  350 PRINT 2005
      PRINT 2006
      IF (UNITS .EQ. 1) PRINT 2007,RAIN,VERTOZ
      IF(UNITS.EQ. 1) PRINT 2009
      IF(UNITS.EQ. 1) GO TO  355
      PRINT 3007 , RAIN, VERTOZ
      PRINT 2008
 2005 FORMAT(* LATERAL DIST       AUDIBLE NOISE          RADIO INTERFERENCE
     1*          *          TVI                  OZONE  *  )
 2006 FORMAT(*     FROM            TOTALS (RAIN)       RAIN      RAIN      *
     1        *FAIR          TOTAL        FOR RAIN RATE OF  *  )
 2007 FORMAT(*  CENTERLINE        L5         L50         HEAVY     L50       *
```

```
     1          *L50          RAIN* F8.2 * IN/HR AT * F2.0 * FT.LEVEL * )
 3007 FORMAT(*  CENTERLINE          L5          L50          HEAVY     L50          *
     1          *L50          RAIN* F8.2 * MM/HR AT * F2.0 * M LEVEL  * )
 2008 FORMAT(*    (METERS)          DBA         DBA          DBUV/M    DBUV/M     *
     1          *DBUV/M       DBUV/M                 PPHM  *  /  )
 2009 FORMAT(*     (FEET)           DBA         DBA          DBUV/M    DBUV/M     *
     1          *DBUV/M       DBUV/M                 PPHM  *  /  )
10015 FORMAT(F9.1,4X,F10.1,F9.1,F10.1, F9.1,F 9.1,2X,F10.1,8X,F10.4)
  355 WRITE(6,10015)(DIS (I),SLAL5(I),SLAL50(I),HRAIN(I),ARAIN(I),
     1  PIFAIR(I),TVMAX(I),OZONE(I),I=1,NPTF)
      GO TO 19
C
CONVERT METRIC TO ENGLISH
C
  800 VERTAN = VERTAN*3.28
      VERTRI = VERTRI*3.28
      VERTTV = VERTTV*3.28
      VERTOZ = VERTOZ*3.28
      WIND = WIND/.447
      RAIN=RAIN/25.4
      DO 805 I= 1,NC
      SUBSPC(I)=SUBSPC(I)/2.54
      X(I)=X(I)*3.28
      Y(I)=Y(I)*3.28
      P(I)=P(I)*1.60934
  805 DIAM(I)=DIAM(I)/25.4
      DO 810 M= 1,NPTF
  810 DIS(M) = DIS(M)*3.28
      GO TO 300
C
  195 STOP
      END
```

```
      SUBROUTINE AN (SLALE,SLALSO,VERTAN)
      COMMON/AREA/NEH,FREQEI,FREQTV,X(10),Y(10),GRAD(10),DIAM(10),ANR(10
     1),          NCOMB,NPT,SC,DI,NETE,TITLE(2,12),DIS(50),UNITS,
     2   EAZNUM(10)
      DIMENSION SLA(6),SLACON(6),PWL(6),          RSQ(6),R(6),DEQ(6)
     1  ,SLALS( 50),SLALSO( 50)
      INTEGER UNITS
   23 FORMAT(1H1)
  600 FORMAT( F10.1,5F10.1,2X,3F10.1)
  999 FORMAT (1H0)
 2015 FORMAT(1X,* MICROPHONE HT.=*F5.1* METERS *//)
 2016 FORMAT(1X,* MICROPHONE HT.=*F5.1* FEET* // )
10002 FORMAT(*  DIST FROM      TOTALS (RAIN)      PHASE A   PHASE B   PHAS
     1E C  *)
10003 FORMAT(*  CENTERLINE    L5          L50         L50         L50         L5
     1C    *)
10004 FORMAT(*  (METERS)      (DBA)       (DBA)       (DBA)       (DBA)       (DB
     1A)   * /)
 2004 FORMAT(*   (FEET)       (DBA)       (DBA)       (DBA)       (DBA)       (DB
     1A)   * /)
10005 FORMAT(*  DIST FROM      TOTALS (RAIN)      PHASE A1  PHASE B1  PHAS
     1E C1    PHASE A2  PHASE B2  PHASE C2*)
10006 FORMAT(1X ,            A8          ,4X, F9.2,6X,F6.2,F9.2,F9.2,5X,F2)
10007  FORMAT(11X,*CENTER OF TOWER  HEIGHT  GRADIENT   DIAM.   SUBCON.*)
10008 FORMAT(14X,*DIST. FROM*,13X,*MAXIMUM  SUBCON.  NO. OF*)
10009 FORMAT(15X,*(METERS)*4X*(METERS)*2X*(KV/CM)*3X*(MM)*/)
 2009 FORMAT(15X,* (FEET)  *4X* (FEET)  *2X*(KV/CM)*3X*(IN)*/)
10010 FORMAT(*  CENTERLINE    L5          L50         L50         L50         L5
     1D          L50         L50         L50   *)
10011 FORMAT(*  (METERS)      (DBA)       (DBA)       (DBA)       (DBA)       (DB
     1A)         (DBA)       (DBA)       (DBA)     */)
 2011 FORMAT(*   (FEET)       (DBA)       (DBA)       (DBA)       (DBA)       (DB
     1A)         (DBA)       (DBA)       (DBA)     */)
31000 FORMAT  (* AUDIBLE NOISE CALCULATIONS EQUIVALENT DIAMETER FORMULA*
     1     // )
      VERT=VERTAN
      IF(NCOMB.EQ.1)GO TO 189
      WRITE(6,23)
      WRITE(6,31000)
      DO 20 L=1,2
   20 WRITE(6,21)(TITLE(L,K),K=1,12)
   21 FORMAT(1X,12A6)
      WRITE(6,999)
      WRITE(6,10002)
```

```
      WRITE(6,10007)
      IF(UNITS.EQ. 1) PRINT 2009
      IF(UNITS.EQ. 1) GO TO 200
      WRITE(6,10009)
      DO 35 I=1,NPH
      WRITE(6,10008)FAZNUM(I),X(I),Y(I),GRAD(I),DIAM(I),    ANR(I)
   35 CONTINUE
      PRINT 999
      PRINT 2015,VERT
   36 CONTINUE
      IF(NPH.EQ.5) GO TO 186
      WRITE(6,10002)
      WRITE(6,10003)
      IF(UNITS.EQ. 1) PRINT 2004
      IF(UNITS.EQ. 1) GO TO 188
      WRITE(6,10004)
      GO TO 188
  200 DO 235 I=1,NPH
      X(I)=X(I)*3.28
      Y(I)=Y(I)*3.28
      DIAM(I)=DIAM(I)/25.4
      PRINT 10006,FAZNUM(I),X(I),Y(I),GRAD(I),DIAM(I),ANR(I)
      X(I)=X(I)/3.28
      Y(I)=Y(I)/3.28
      DIAM(I)=DIAM(I)*25.4
  235 CONTINUE
      PRINT 999
      VERT=VERT*3.28
      PRINT 2016,VERT
      VERT=VERT/3.28
      GO TO 36
  186 WRITE(6,10008)
      WRITE(6,10010)
      IF(UNITS.EQ. 1) PRINT 2011
      IF(UNITS.EQ. 1) GO TO 188
      WRITE(6,10011)
  188 CONTINUE
      NPT=NPTF
      DO 500 H = 1,NPT
      DO 40  I = 1,NPH
      D=DIS (H)
      RSQ(I) = (Y(I)-VERT)**2 +(D - X(I))**2
      R(I) = SQRT(RSQ(I))
      XX = ANR(I)
      IF(XX.LT.4.) GO TO 78
```

```
      DEQ(I) = 0.589*DIAM(I)*AN2(I)**0.482
      GO TO 79
   76 DEQ(I) = DIAM(I)
   73 PWL(I) = -164.7 + 120.0*ALOG10(GRAD(I)) + 55.0*ALOG10(DEQ(I))
      SLA(I) = PWL(I) - 11.4*ALOG10(R(I)) - 5.5
   40 SLACON(I) = 10.**(SLA(I)/10.)
      SLATOT = 0.0
      DO 94 I = 1,NEH
   94 SLATOT = SLATOT + SLACON(I)
      SLALEQ(M) = 10.0*ALOG10(SLATOT)
      SLALE(M) = SLALEQ(M) + 3.5
      IF (NCOMB .EQ. 1) GO TO 600
      IF(UNITS.EQ. 1) D=D*3.28
      WRITE(6,600) D,SLALE(M),SLALEQ(M),(SLA(J),J=1,NEH)
  600 CONTINUE
  135 RETURN
      END
```

```
      SUBROUTINE RI (HRAIN ,RIFAIR,VERTRI,ARAIN)
      COMMON/AREA/NEH,FREQRI,FREQT1,X(10),Y(10),GRAD(10),DIAM(10),ANR(10
     1),          NCOMS,NET,SD,DI,NRTF,TITLE(2,12),DIS(50),UNITS,
     2   FAZNUM(10)
      DIMENSION HRAIN(50),RIFAIR(50),R(6),E(6),RSG(6),EPHASE(6),ARAIN(50
     1   )
      INTEGER UNITS
   23 FORMAT(1H1)
  800 FORMAT(  F9.1,5F10.1,2X,3F10.1)
  999 FORMAT (1H0)
 10001 FORMAT (14H  ANTENNA HT.=,F5.1,7H METERS,8H, FREQ.=,F7.3,4H MHZ,//
     1   )
 2001 FORMAT (14H  ANTENNA HT.=,F5.1,7H  FEET ,8H, FREQ.=,F7.3,4H MHZ,//
     1   )
 10002 FORMAT(*  DIST FROM    HEAVY      FAIR      PHASE A   PHASE B   PHAS
     1E C  *)
 10003 FORMAT(*  CENTERLINE   RAIN     WEATHER      RI         RI         RI
     1      *)
 10004 FORMAT(*  (METERS)     (DB)       (DB)       (DB)       (DB)       (DB
     1)    */ )
 2004 FORMAT(*   (FEET)      (DB)       (DB)       (DB)       (DB)       (DB
     1)    */ )
 10005 FORMAT(*  DIST FROM    HEAVY      FAIR      PHASE A1  PHASE B1  PHAS
     1E C1  PHASE A2  PHASE B2  PHASE C2  *)
 10006 FORMAT(1X ,            A2        ,4X, F9.2,5X,F9.2,F9.2,F9.2,5X,F2)
 10007  FORMAT(11X,*CENTER OF TOWER  HEIGHT  GRADIENT   DIAM.   SUBCON.*)
 10008 FORMAT(14X,*DIST. FROM*,13X,*MAXIMUM  SUBCON.  NO. OF*)
 10009 FORMAT(15X,*(METERS) *4X*(METERS)*2X*(KV/CM)*3X*(MM)*/)
 2009 FORMAT(15X,*  (FEET)  *4X*  (FEET)  *2X*(KV/CM)*3X*(IN)*/)
 10010 FORMAT(*  CENTERLINE   RAIN     WEATHER      RI         RI         RI
     1        RI         RI         RI     *)
 10011 FORMAT(*  (METERS)     (DB)       (DB)       (DB)       (DB)       (DB
     1)       (DB)       (DB)       (DB)     * / )
 2011 FORMAT(*   (FEET)      (DB)       (DB)       (DB)       (DB)       (DB
     1)       (DB)       (DB)       (DB)     * / )
 31000 FORMAT (* RADIO NOISE CALCULATIONS WESTINGHOUSE SIMPLE FORMULA*//)
      VERT=VERTRI
      IF(NCOMS.EQ.1)GO TO 188
      WRITE(6,23)
      WRITE(6,31000)
      DO 20 L=1,2
   20 WRITE(6,21)(TITLE(L,K),K=1,12)
   21 FORMAT(1X,12A6)
      PRINT 999
```

```
      WRITE(6,10008)
      WRITE(6,10007)
      IF(UNITS.EQ. 1) PRINT 2009
      IF(UNITS.EQ. 1) GO TO 200
      WRITE(6,10003)
      DO 35 I=1,NPH
      WRITE(6,10006)FAZNUM(I),X(I),Y(I),GRAD(I),DIAM(I),    ANR(I)
   35 CONTINUE
      WRITE(6,999)
      WRITE (6,10001) VERT,FREQRI
  250 CONTINUE
      IF(NPH.EQ.6) GO TO 185
      WRITE(6,10002)
      WRITE(6,10003)
      IF(UNITS.EQ. 1) PRINT 2004
      IF(UNITS.EQ. 1) GO TO 185
      WRITE(6,10004)
      GO TO 185
  200 DO 235 I=1,NPH
      Y(I)=Y(I)*3.28
      X(I)=X(I)*3.28
      DIAM(I)=DIAM(I)/25.4
      PRINT 10006,FAZNUM(I),X(I),Y(I),GRAD(I),DIAM(I),ANR(I)
      X(I)=X(I)/3.28
      Y(I)=Y(I)/3.28
      DIAM(I)=DIAM(I)*25.4
  235 CONTINUE
      PRINT 999
      VERT=VERT*3.28
      PRINT  2001,VERT,FREQRI
      VERT=VERT/3.28
      GO TO 250
  185 WRITE(6,10005)
      WRITE(6,10010)
      IF(UNITS.EQ. 1) PRINT 2011
      IF(UNITS.EQ. 1) GO TO 188
      WRITE(6,10011)
  188 WL = 300./ FREQRI
      CH = WL/6.283185308
      R = CH**2
      NPT=NPTF
      DO 500 M = 1,NPT
      DO 40 I = 1,NPH
      D= DIS(M)
      RSQ(I)=(Y(I)-VERT)**2 + (D - X(I))**2
```

```
      R(I) = SQRT(RSQ(I))
      A = R(I)
      IF (A.GT.DH) 98,99
   98 E(I) = 48.0 + 3.5*(GRAD(I)-17.5) + 30.*ALOG10(DIAM(I)/35.1)
     1 + 20.*ALOG10((30.7*Y(I))/R) + 20.*ALOG10(DH/R(I)) + 10.*(1.-FREQR
     1I)
      GO TO 39
   99 E(I) = 48.0 + 3.5*(GRAD(I)-17.5) + 30.*ALOG10(DIAM(I)/35.1)
     1 + 20.*ALOG10((30.7*Y(I))/RSQ(I)) + 10.*(1.-FREQRI)
      GO TO 39
   31 E(I) = 48.0 +2.48*(GRAD(I)-17.5) + 30.*ALOG10(DIAM(I)/35.1)
     1 + 20.*ALOG10((30.7*Y(I))/RSQ(I)) + 10.*(1.-FREQRI)
   39 EPHASE(I) = E(I)
   40 CONTINUE
      EMAX = AMAX1(E(1),E(2),E(3))
      IF(NPH.EQ.3) GO TO 395
      EMAX = AMAX1(E(4),E(5),E(6))
      EMAX= AMAX1(EMAX,EMAX)
  395 HRAIN(M)= EMAX + 24.0
      EIRAIR(M)=EMAX
      ARAIN(M)=EMAX+17.0
      IF (NCOMB .EQ. 1) GO TO 500
      IF(UNITS.EQ. 1) D=D*3.28
      WRITE(6,600) D,HRAIN(M),EMAX,(EPHASE(J),J=1,NPH)
  600 CONTINUE
  100 RETURN
      END
```

```
      SUBROUTINE TVI (TVMAX ,VERTTV)
      COMMON/AREA/NFH,FREQFI,FREQTV,X(10),Y(10),GRAD(10),DIAM(10),ANR(10
     1),          NCOMS,NET,SD,DI,NPTF,TITLE(2,12),DIS(50),UNITS,
     2   FAZNUM(10)
      DIMENSION ESQ(6),R(6),E(6),EPHASE(6),TVMAX(50)
      INTEGER UNITS
   23 FORMAT(1H1)
  600 FORMAT( F8.1,7X,F8.1,6X,3F10.1,2X,3F10.1)
  999 FORMAT (1H0)
10001 FORMAT (14H  ANTENNA HT.=,F5.1,7H METERS,8H, FREQ.=,F7.3,4H MHZ,//
     1    )
 2001 FORMAT (14H  ANTENNA HT.=,F5.1,7H  FEET ,8H, FREQ.=,F7.3,4H MHZ,//
     1    )
10002 FORMAT(*  DIST FROM      TOTALS (RAIN)      PHASE A   PHASE B   PHAS
     1E C  *)
10003 FORMAT(*  CENTERLINE      QUASI-PEAK          QP        QP        QP
     1      *)
10004 FORMAT(*  (METERS)         DBUV/M           DBUV/M    DBUV/M    DBUV
     1/M   */ )
 2004 FORMAT(*   (FEET)          DBUV/M           DBUV/M    DBUV/M    DBUV
     1/M   */ )
10005 FORMAT(*  DIST FROM      TOTALS (RAIN)      PHASE A1  PHASE B1  PHAS
     1E C1    PHASE A2  PHASE B2  PHASE C2   *)
10006 FORMAT(1X ,            A8          ,4X, F5.2,6X,F6.2,F9.2,F9.2,5X,F2)
10007  FORMAT(11X,*CENTER OF TOWER  HEIGHT  GRADIENT   DIAM.   SUBCON.*)
10008 FORMAT(14X,*DIST. FROM*,13X,*MAXIMUM  SUBCON.  NO. CF*)
10009 FORMAT(15X,*(METERS)*4X*(METERS)*2X*(KV/CM)*3X*(MM)*/)
 2009 FORMAT(15X,* (FEET) *4X* (FEET) *2X*(KV/CM)*3X*(IN)*/)
10010 FORMAT(*  CENTERLINE      QUASI-PEAK          QP        QP        QP
     1          QP        QP        QP   *)
10011 FORMAT(*  (METERS)         DBUV/M           DBUV/M    DBUV/M    DBUV
     1/M      DBUV/M    DBUV/M    DBUV/M   * / )
 2011 FORMAT(*   (FEET)          DBUV/M           DBUV/M    DBUV/M    DBUV
     1/M      DBUV/M    DBUV/M    DBUV/M   * / )
10012 FORMAT(1H0* TVI CALCULATIONS, QP DETECTOR, STODDART NM30A METER *
     1    // )
      VERT=VERTTV
      IF(NCOMS.EQ.1)GO TO 188
      WRITE(6,23)
      PRINT 10012
      DO 20 L=1,2
   20 WRITE(6,21)(TITLE(L,K),K=1,12)
   21 FORMAT(1X,12A6)
      WRITE(6,999)
```

```
      WRITE(6,10008)
      WRITE(6,10007)
      IF(UNITS.EQ. 1) PRINT 2009
      IF(UNITS.EQ. 1) GO TO 200
      WRITE(6,10009)
      DO 35 I=1,NPH
      WRITE(6,10006)FAZNUM(I),X(I),Y(I),GRAD(I),DIAM(I),    ANR(I)
   35 CONTINUE
      WRITE(6,999)
      WRITE (6,10001) VERT,FREQTV
  250 CONTINUE
      IF(NPH.EQ.6) GO TO 186
      WRITE(6,10002)
      WRITE(6,10003)
      IF(UNITS.EQ. 1) PRINT 2004
      IF(UNITS.EQ. 1) GO TO 188
      WRITE(6,10004)
      GO TO 189
  200 DO 235 I=1,NPH
      X(I)=X(I)*3.28
      Y(I)=Y(I)*3.28
      DIAM(I)=DIAM(I)/25.4
      PRINT 10006,FAZNUM(I),X(I),Y(I),GRAD(I),DIAM(I),ANR(I)
      X(I)=X(I)/3.28
      Y(I)=Y(I)/3.28
      DIAM(I)=DIAM(I)*25.4
  235 CONTINUE
      PRINT 999
      VERT=VERT*3.28
      PRINT  2001,VERT,FREQTV
      VERT=VERT/3.28
      GO TO 250
  186 WRITE(6,10005)
      WRITE(6,10010)
      IF(UNITS.EQ. 1) PRINT 2011
      IF(UNITS.EQ. 1) GO TO 188
      WRITE(6,10011)
  188 CONTINUE
      NPT=NPTF
      DO 500 M=1,NPT
      DO 40  I=1,NPH
      D=DIS (M)
      RSQ(I) = (Y(I)-VERT)**2 + (D-X(I))**2
      R(I) = SQRT(RSQ(I))
      CH=12.0 * VERT * Y(I) * FREQTV *3.28       / 984.2344
```

```
      E(I) = 10.0 + 3.3 * (GRAD(I) - 16.3) + 30. * ALOG10(DIAM(I)/30.0)+
     1 20. * ALOG10(75./FREQTV)
      A = E(I)
      IF(61.LT.CH.AND.A.LT.CH)  E(I)=E(I)+20.0*ALOG10(61.0/A)
      IF(61.LT.CH.AND.A.GT.CH)E(I)=E(I)+20.0*ALOG10(61.0/CH)+40.0*
     1  ALOG10(CH/A)
      IF(61.GT.CH.AND.A.LT.CH)E(I)=E(I)+40.0*ALOG10(61.0/CH)+20.0*ALOG10
     1   (CH/A)
      IF(61.GT.CH.AND.A.GT.CH)  E(I)=E(I)+ 40.0*ALOG10(61.0/A)
   30 EPHASE(I) = E(I)
   40 CONTINUE
      EMAX =AMAX1(E(1),E(2),E(3))
      IF(NPH .EQ. 3) GO TO 390
      EMAX = AMAX1(E(4),E(5),E(6))
      EMAX= AMAX1(EMAX,EMAX)
  390 TVMAX(M) = EMAX
      IF (NOOMB .EQ. 1) GO TO 500
      IF(UNITS.EQ. 1) D=D*3.28
      WRITE(6,600) D,EMAX,(EPHASE(J),J=1,NPH)
  500 CONTINUE
  190 RETURN
      END
```

```
      SUBROUTINE OZ( WIND, RAIN, VOLTLL,OZONE, VERTOZ , P )
      COMMON/AREA/NPH,FREQRI,FREQTW,X(10),Y(10),GRAD(10),DIAM(10),ANR(10
     1),            NCOMB,NPT,SD,DI,NPTF,TITLE(2,12),DIS(50),UNITS,
     2   FAZNUM(10)
      DIMENSION S(6),P(6),GG(6),C(50),RAD(6),OZONE(50)
      INTEGER UNITS
      VOLTLN = VOLTLL/SQRT(3.0)
      DATA CFACT/0.467E08/
      DATA PI/3.14269265/
      WIND1=WIND
      SBAR=0.0
      IF(NCOMB.EQ. 1) GO TO 40
      PRINT 2000
 2000 FORMAT(1H1)
      PRINT 23,((TITLE(L,K),K=1,12),L=1,2)
      PRINT 999
   40 CONTINUE
      DO 10 NN=1,NPH
      RAD(NN)=DIAM(NN)/20.0
   10 CONTINUE
      DO 6 I=1,NPH
      P(I)= (.021*RAD(I)*RAD(I)* ANR(I)*EXP( 0.27*GRAD(I)))/
     1        (123.0 * EXP( -0.22 * GRAD(I))/ RAIN + 1.0)
      GG(I)= GRAD(I) / VOLTLN
      S(I) = P(I) * GG(I) * GG(I) * 1.260E-07
      MM=I
    6 SBAR = SBAR + S(I)
      SBAR = SBAR / MM
      IF(NCOMB.EQ. 1) GO TO 100
      DO 30  I=1,NPH
   30 PRINT 211,I,X(I),I,Y(I), I,S(I), GRAD(I),P(I),ANR(I)
      PRINT 2001,RAIN
 2001 FORMAT(1H0,* RAIN = * F8.0, * MM/HR. * )
      PRINT 999
      WRITE( 6,202)       WIND1,SBAR
   23 FORMAT(1X,12A6)
  999 FORMAT( *  * )
  211 FORMAT(1X*X(*I2*) = *F6.1* METERS, Y(*I2*) = *F6.1* METERS, S(*I2*
     1) = *E9.3* KG/M/SEC.*,3F8.3)
  202 FORMAT(1X,*WIND VELOCITY = *                    F7.3 * METERS/SEC, S(NE
     1AN) = *E9.3* KG/M/SEC.*///50X*OZONE CONCENTRATION IN PPHM*// )
      PRINT 300
      PRINT 305
  300 FORMAT(* HEIGHT *38X* LATERAL DISTANCE FROM CENTERLINE (METERS)*)
```

```
305 FORMAT(1H0,15X,*3*10X*5*9X*10*9X *15*9X*20*9X *25*8X* 50* 8X* 75*
    1    8X*100* 8X*125*8X*150*  )
    DO 15 JJ=3,55,5
    JI=JJ-5
    G=JI
    DO 12 I=1,11
 12 C(I)=0.0
    M=0
    DO 14 I=1,2
    KK0=KK1=KK3=5
    KK2=30
    IF(I.EQ.1)20,19
 19 KK1=50
    KK0=0
    KK2=150
    KK3=25
 20 CONTINUE
    DO 14 KK=KK1,KK2,KK3
    H=KK-KK0
    M=M+1
    DO 14 L=1,NPH
    XL=H-X(L)
    IF(XL.LT..25)14,13
 13 SIG=.0315*(23./WIND1+4.75*(100./Y(L))**.25)*(H-X(L))**.86
    A=(ABS(G-Y(L)))**2./(2.*SIG**2.)
    B=(G+Y(L))**2./(2.*SIG**2.)
    C1=SBAR/(WIND1*SIG*SQRT(2.*PI))
    C(M)=C(M)+C1*(1./EXP(A)+1./EXP(B))
 14 CONTINUE
    DO 18 I=1,11
 18 C(I)=C(I)*CFACT
    WRITE(   6,206)JI,(C(I),I=1,11)
206 FORMAT(1H0,X,I3,2X,11F11.4)
 15 CONTINUE
    IF(NCOMB.NE.1) GO TO 25
100 CONTINUE
    DO 105 M=1,NPTF
    C(M)=0.0
    DO 105 L=1,NPH
    XL=DIS(M)-X(L)
    IF(XL.LT..25) GO TO 105
    SIG=.0315*(23./WIND1+4.75*(100./Y(L))**.25)*( XL   ) **.86
    A =(Y(L)-VERTOZ) * ( Y(L)-VERTOZ)  / (2.0 * SIG * SIG )
    B =(Y(L)+VERTOZ) * ( Y(L)+VERTOZ)  / (2.0 * SIG * SIG )
    C1=SBAR/(WIND1*SIG*SQRT(2.*PI))
```

```
      C(M)=C(M)+C1*(1./EXP(A)+1./EXP(B))
  135 CONTINUE
      DO 110 I= 1,NETF
      C(I) = C(I) * CFACT
      CZONE(I)=C(I)
  110 CONTINUE
   25 RETURN
      END
```

```
      SUBROUTINE MANGO  (X,Y,DIAM,V,PH,  ANR,SUBSPC,ERR ,NC )
      DIMENSION X(10),Y(10),DIAM(10),BUNDIA(10),ANR(10),SUBSPC(10)
     1  ,P(10,10),Q(10),V(10),DEQ(10),RAD(10),ERR(10),DIA(10),CK2(10),
     2  QREAL(10),QIMAG(10),VREAL(10),VIMAG(10),PH(10)
      PI = 3.141592654
      EPS = (1.0 / (36.0 * PI )) * 1.0 E-09
      EPSI = 1.0 / (2.0 * PI * EPS )
      DO 10 I= 1,NC
      VREAL(I)= V(I)* COS(PH(I)*PI / 180.0) * 1000.0
      VIMAG(I)= V(I)* SIN(PH(I)*PI / 180.0) * 1000.0
      DIA (I) = DIAM(I)/10.0
      RAD(I) = DIA (I) / 2.0
      IF (ANR(I) .EQ.1.0) SUBSPC(I) = RAD(I)
      IF(ANR(I).EQ.1.0) GO TO 5
       BUNDIA(I) =SUBSPC(I)/SIN(PI/ANR(I))
    5 IF(ANR(I).EQ.1.0) BUNDIA(I) = DIA (I)
      DEQ(I) =(BUNDIA(I)*(ANR(I)* DIA (I)/BUNDIA(I)) ** (1.0/ANR(I)) )
     1     / 100.0
   10 CONTINUE
      DO 40 I= 1,NC
      DO 30 J= 1,NC
      IF ( I.EQ.J) GO TO 20
      P(I,J) = EPSI*ALOG(   SQRT(( X(I)-X(J) )**2  + ( Y(I)+Y(J) )**2 )/
     1                SQRT(( X(I)-X(J) )**2  + ( Y(I)-Y(J)  )**2 )    )
      GO TO 30
   20 P(I,J) = EPSI * ALOG( Y(J) * 4.0 / DEQ(I)  )
   30 CONTINUE
   40 CONTINUE
      CALL MATRIX (10,NC,NC,2,P,10,DET)
      CALL MATRIX(20,NC,NC,1,P,10,VREAL,10,QREAL,10)
      CALL MATRIX(20,NC,NC,1,P,10,VIMAG,10,QIMAG,10)
      DO 170 I = 1,NC
      Q(I)=SQRT( QREAL(I)*QREAL(I) + QIMAG(I)*QIMAG(I) )
  160 CK2(I)=2.0*(ANR (I) - 1.0 ) * SIN (PI/ANR(I) )
  170 CONTINUE
      DO 180 I= 1, NC
      ERR(I)=            Q(I)*(1.0+CK2(I)/(SUBSPC(I)/RAD(I)))*18.0 E06
     1     / (ANR(I) * RAD(I)  )
  180 CONTINUE
      RETURN
      END
```

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